

ATTACHMENT 5 HYDRAULIC APPENDIX



2011

ENVIRONMENTAL MANAGEMENT PROGRAM
US ARMY CORPS OF ENGINEERS
ST. PAUL DISTRICT

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CAPOLI SLOUGH HYDRAULICS APPENDIX

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GENERAL

The Capoli Slough backwater area is located in pool 9, between the Wisconsin shoreline and the main navigation channel from approximate river mile 656.5 to 658.3. The area includes an intermingled complex of stump fields, sloughs, vegetation beds, and island remnants. The general project area is shown in Figure 2.

Capoli Slough runs through the project area and bathymetric surveys indicate that they are deep, ranging from 6 to 15 feet at the average pool elevation of 620.1 ft 1912 msl adjusted. All elevations in this appendix are in 1912 msl adjusted. Outside of these channels, depths range from 1 to 3 feet. This deepwater habitat adjacent to shallower water is important for many fish species and should be protected from sedimentation. Bathymetric and Elevation data is shown in Figure 3.

Comparison of aerial photography of the Capoli Slough area from the 1940's to the present indicated that a rather dramatic loss of emergent landmass has occurred. Few island remnants are present. Tree loss is very apparent. Submerged and floating leaf aquatics are present throughout large portions of the area. As islands have eroded, wind and wave impacts have increased resulting in an increased loss of vegetation. Loss of islands and vegetation beds will reduce the suitability of the area for waterfowl, fish, and other aquatic species.

The objective of this project is to enhance about 2,000 acres of existing waterfowl and fish habitat by providing protection from wind and boat generated waves in the Capoli Slough area and reducing the flow of sediment-laden water into the area. This objective can be accomplished with a combination of island building and existing island bank stabilization. Constructing new islands and stabilizing existing islands in the area will serve an important role of buffering the protected areas from wind & wave effects. This protected "shadow" in and behind the islands will permit aquatic vegetation to become established in the shallow water areas.

EXISTING PHYSICAL CONDITIONS

Mississippi River Hydrology

All of the Mississippi River hydrology data provided here was obtained from the St. Paul District Water Control Center.

Discharge-frequency information at Lock and Dam 9 and the corresponding water surface elevations at Lock and Dam 9 Headwater, the Primary Control Point Gauge at Lansing Iowa, and the interpolated elevation at Harpers Slough and Wexford Creek Delta are shown in Table 1 below. This information is plotted in the Elevation-Frequency curve shown in Chart 1.

Table 1. Discharge-Frequency-Elevation (1912 msl adjusted) at the Project Area					
Frequency (%)	Flow LD9	Flood Event	<u>RM 662.97</u> Lansing Gauge	<u>RM 657.5</u> Capoli Slough	<u>RM 647.9</u> LD9 gauge
50	100,000	2	623.8	623.0	622.5
20	140,500	5	626.8	626.2	625.8
10	167,500	10	628.5	628.2	627.8
4	201,000	25	630.3	629.8	629.5
2	226,000	50	631.4	630.9	630.5
1	251,000	100	632.5	632.2	631.7

Seasonal stage information for the 50%-duration (average water surface elevation) for the project area is provided in Table 2 below.

Table 2. Seasonal Average WSEL (1912 msl adjusted) for project area (50% duration)			
	<u>RM 662.97</u> Lansing Gauge	<u>RM 657.5</u> Capoli Slough	<u>RM 647.9</u> LD9 gauge
All Year	620.39	620.1	619.54
January	620.22	619.9	619.4
February	620.18	619.9	619.44
March	620.55	620.2	619.42
April	620.19	620.15	620.1
May	621.48	620.7	619.75
June	620.82	620.3	619.31
July	620.56	620.1	619.32
August	620.31	620.1	619.58
September	620.34	620.1	619.6
October	620.27	620.1	619.69
November	620.28	620.1	619.52
December	620.29	620.1	619.62

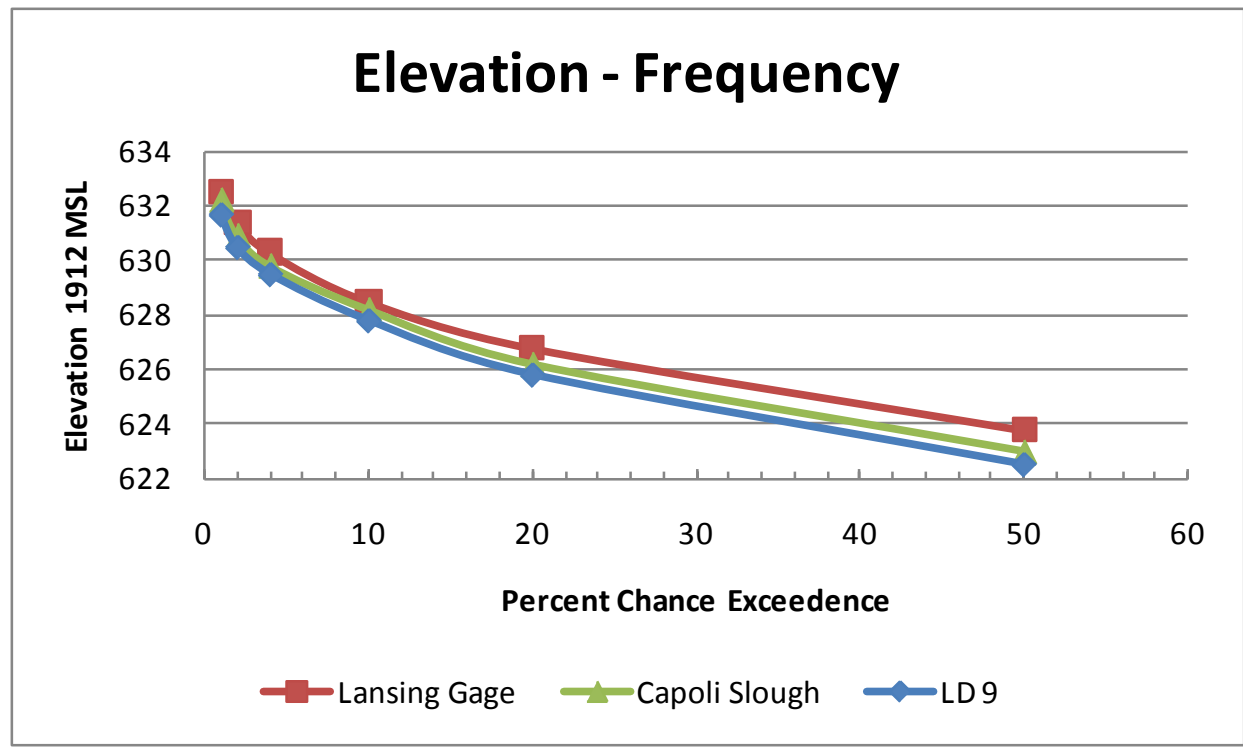
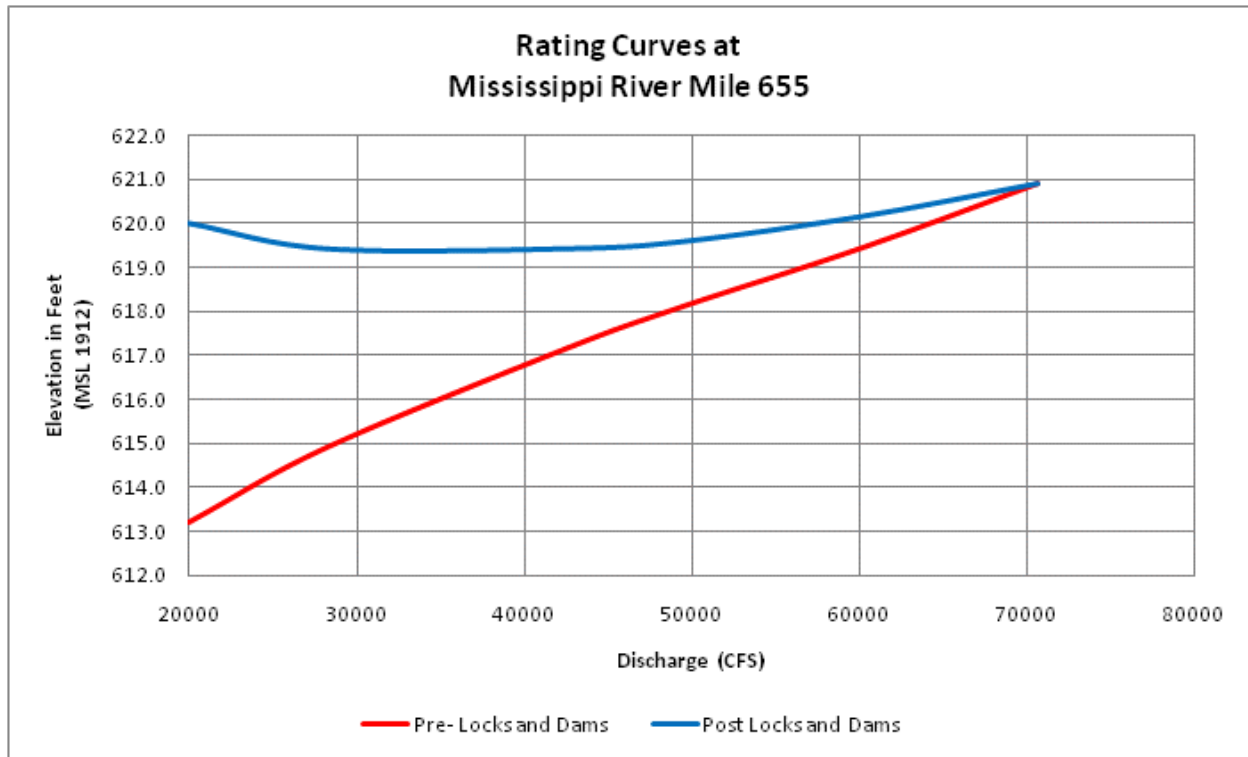


Chart 1

Capoli Slough Hydrology

Hydrodynamics:

The Capoli Slough flow regimes were drastically altered with the construction of Lock and Dam #9. The area provided excellent fish and wildlife habitat immediately after construction, but this habitat has degraded over time. Below, Chart 2 shows the alteration of the rating curve at River Mile 655, which is at the downstream end of the project location.



Discharge Distribution:

The St Paul District Corps of Engineers maintains a database of discharge measurements that have been taken on the Mississippi River in Pools 2 through 10. A map of the discharge measurement locations that are in the project area is shown on Figure 4. At most locations, there is enough data to develop a rating curve. The locations of these measurements are selected such that the rating curves give insight into the distribution of flow between the main channel and the floodplain areas. The rating curves for these locations are shown in Charts 4-9.

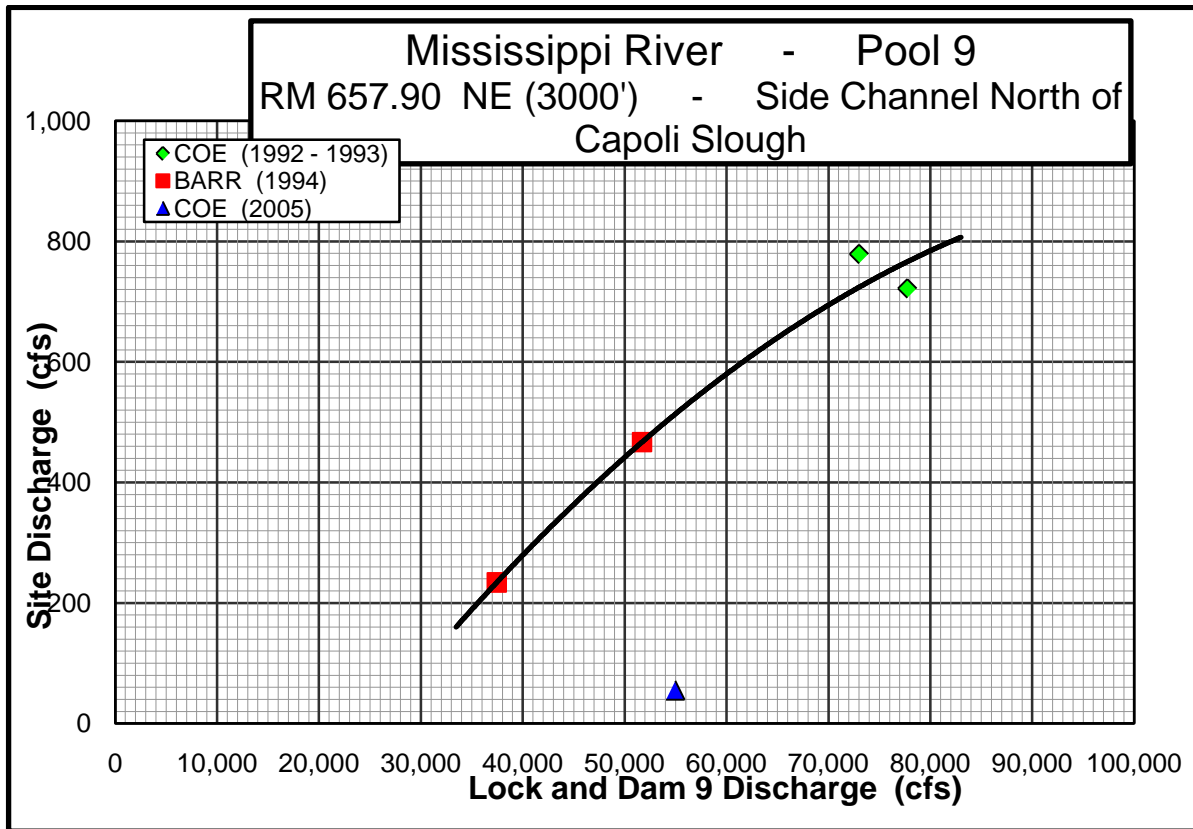


Chart 4

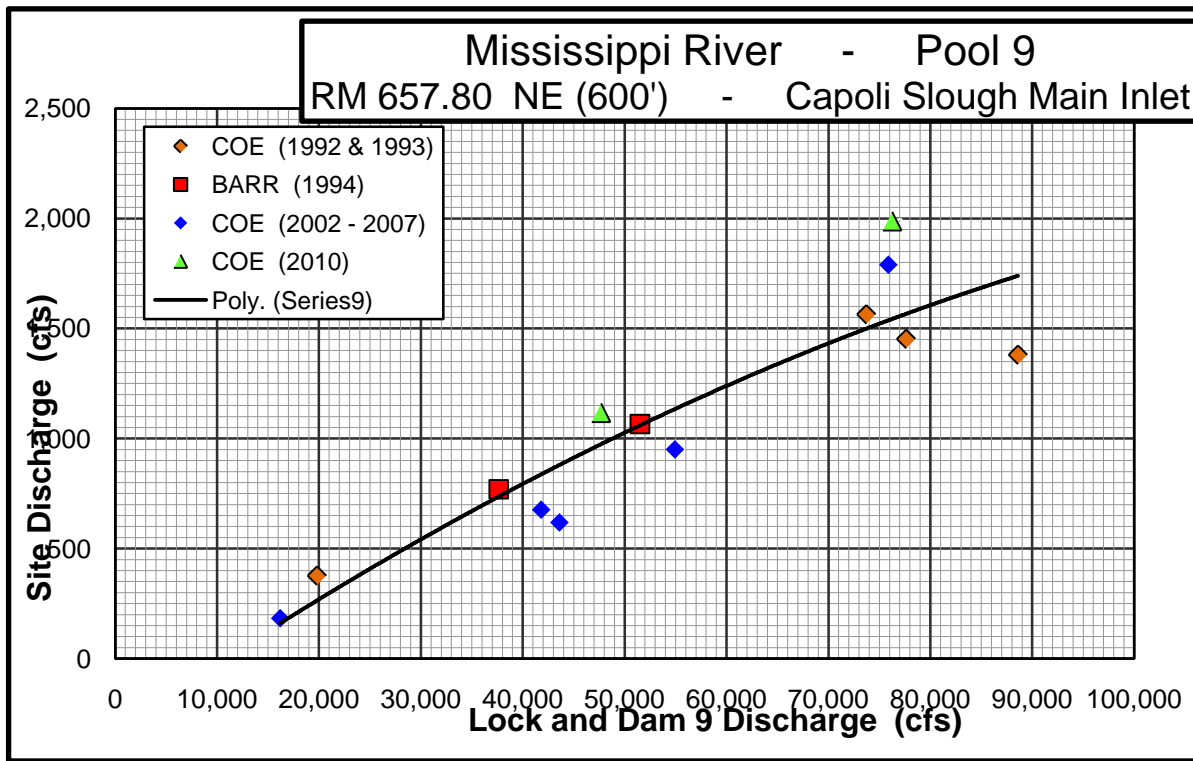


Chart 5

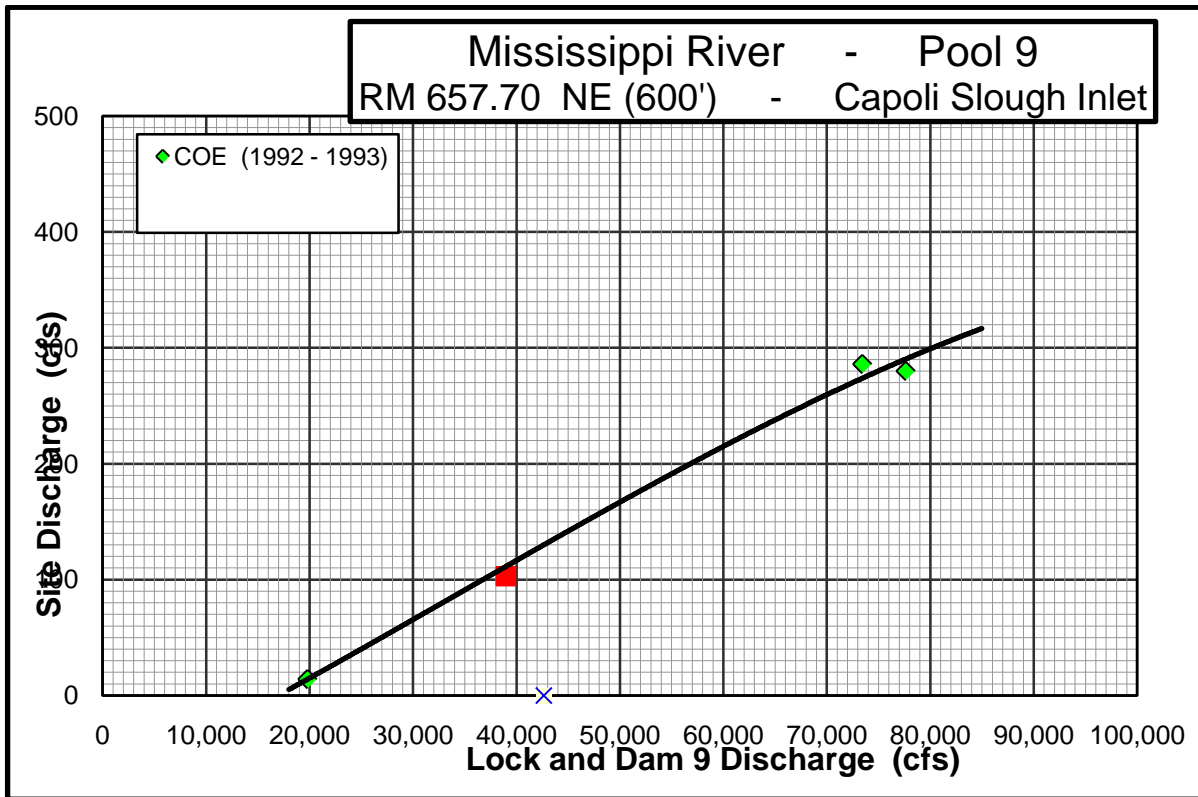


Chart 6

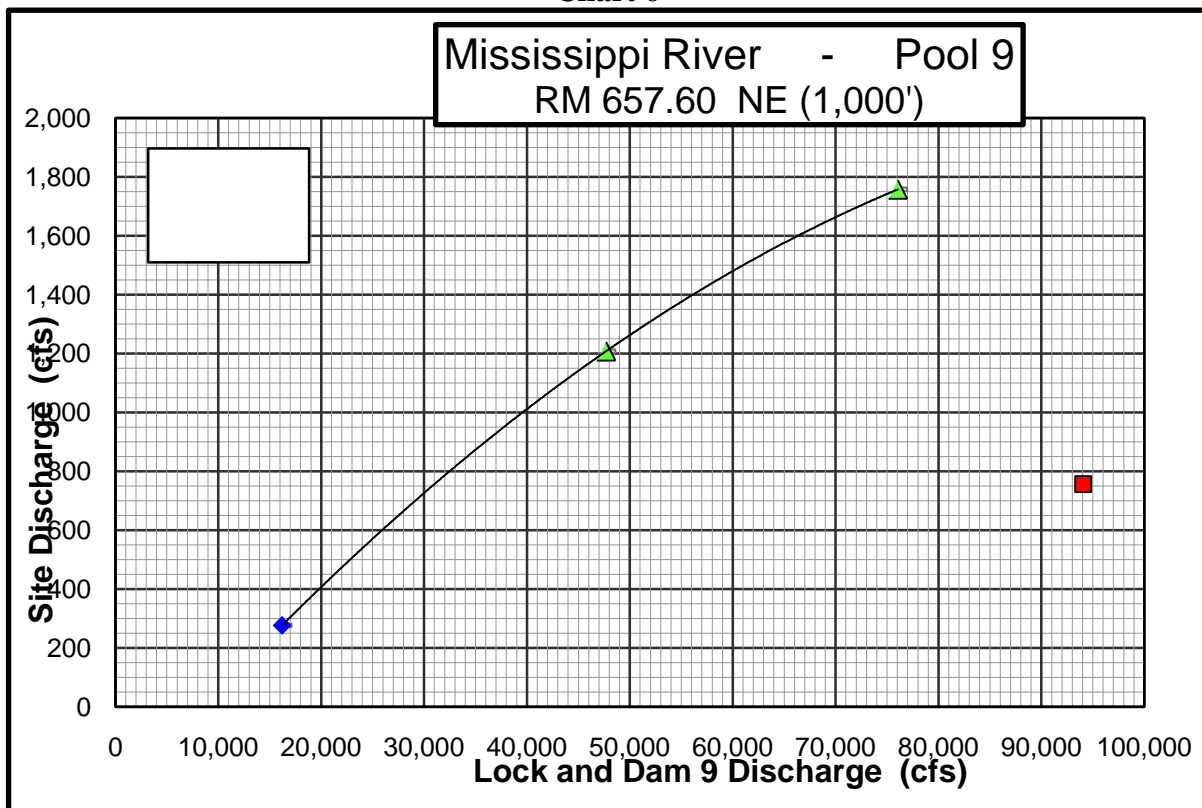


Chart 7

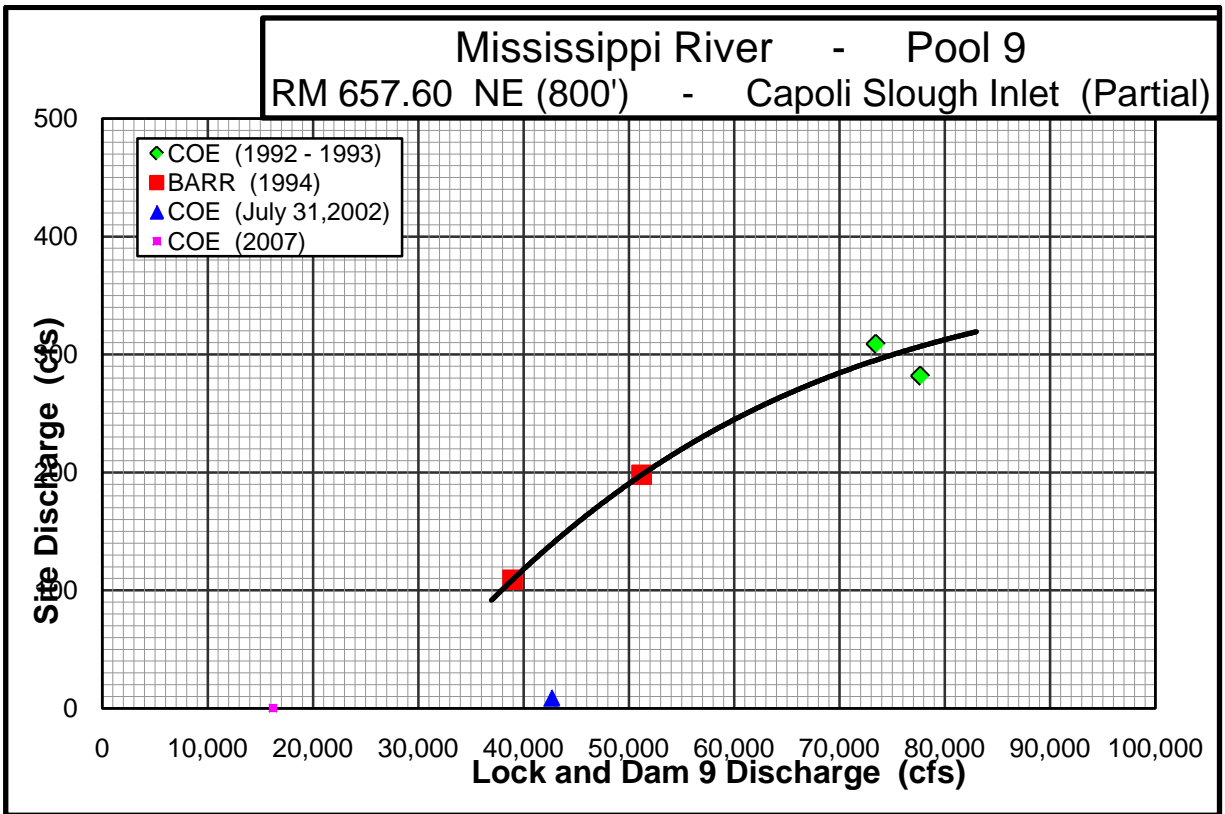


Chart 8

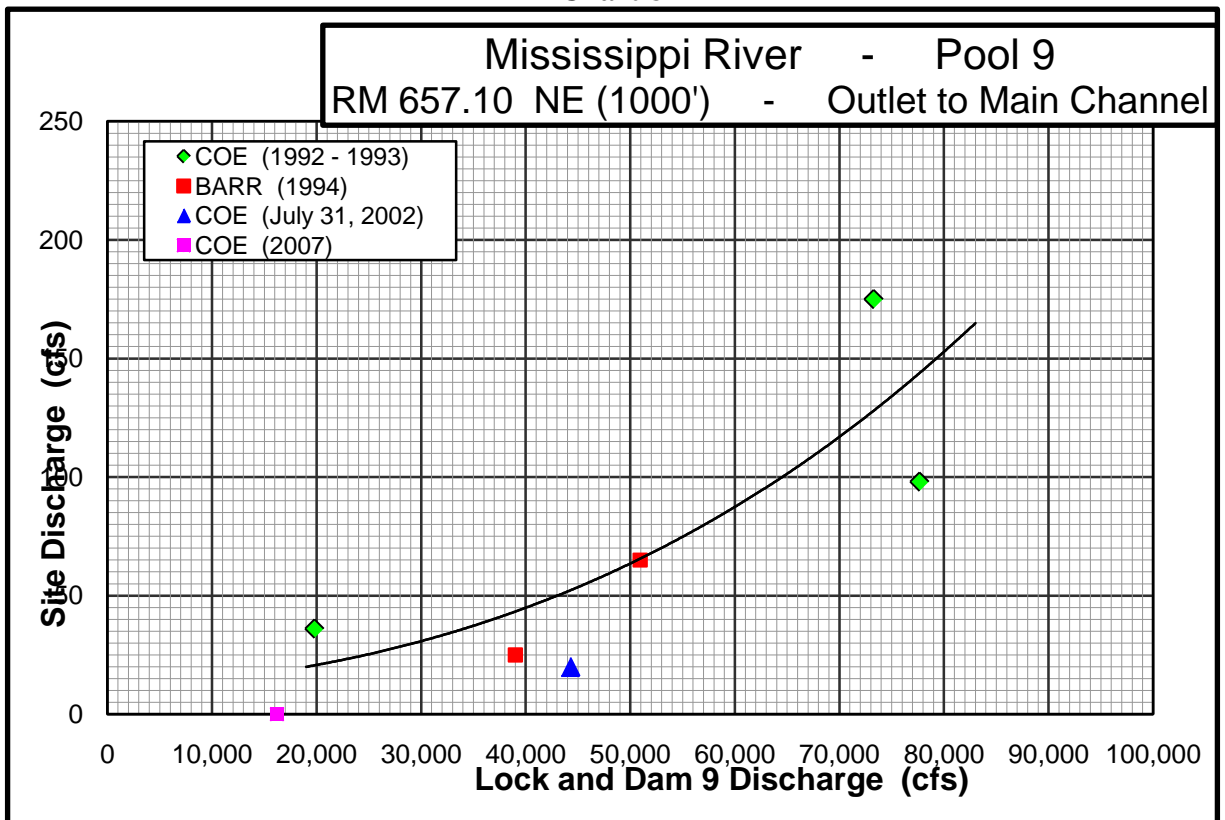


Chart 9

DESIGN OF HYDRAULIC FEATURES

In its natural state the Mississippi River consisted of a main channel, secondary channels, a floodplain, and natural levees that separated the channels from the floodplain. For river flows near bankfull the hydraulic slope of the river reached a maximum, and fluvial processes in the channels such as erosion and deposition also reached a maximum. For river flows well above bankfull (i.e. flood conditions), the natural levees were submerged resulting in water and sediment conveyance in the floodplain. The majority of the conveyance continued to be in the channels though since floodplain resistance was much higher than that in the channels due to woody vegetation. The hydraulic slope of the river remained near maximum and fluvial processes in the channels continued to occur.

Construction of the locks and dams submerged the natural levees and floodplain in the lower ends of the pools resulting in continuous flow of water and sediment through the floodplain for all conditions. The higher parts of the natural levee became islands. Submergence caused changes in the vegetation communities resulting in decreased floodplain resistance and increased floodplain conveyance with time. For river flows near and well above bankfull, the majority of the conveyance is now in the floodplain of the lower pools. This has decreased the hydraulic slope in the pools and subsequently the fluvial processes of erosion and deposition in channels. In the floodplain, there is not enough hydraulic energy for river currents to erode sediments. The result is a less dynamic, depositional river system.

Wind driven wave action has become a much more significant factor in the floodplain of the lower pools, affecting both the transport of sediment and morphological changes in the floodplain. Many of the islands that were formed in the lower pools by submergence of the natural levees subsequently eroded due to wave action. This erosive process continues sometimes until the bed of the river has been lowered to a depth two or three feet below the average water surface elevation. Natural levee formation along the main channel is suppressed due to the erosive action of waves.

By constructing islands, the natural levees that were submerged and subsequently eroded by wave action are being rebuilt. This separates the main channel and secondary channels from the floodplain of the river creating hydrodynamic and fluvial variability. Islands reduce floodplain conveyance and restore the hydraulic energy in adjacent channels necessary for erosion and transport of sediment. Islands reduce wave action and erosion on shorelines that are in the protected area of the island.

The Capoli Slough design is based on:

- Past design/experience/monitoring
- Project Goals/Objectives/Criteria
- Geomorphic, Engineering and Constructability Design Factors
- Other design factors such as economics and aesthetics.

List Of Project Features

Existing Islands:

1. 1
2. 2
3. 3
4. 4
5. 6
6. 7
7. 8
8. 9
9. 10
10. 11

Typical Islands:

11. C
12. G
13. K

Narrow Islands:

1. A
2. B
3. D
4. F
5. H
6. J
7. L
8. E
9. E1

Rock Mounds:

1. I

Rock Sills:

1. A
2. D
3. E

Cobble Liners:

1. A
2. B

Emergent Wetlands:

1. A
2. K

Bank Stabilization:

1. Vanes (Islands C, G, L, E & K)

Fish Habitat Dredging:

1. Fine Borrow A

Island Layout

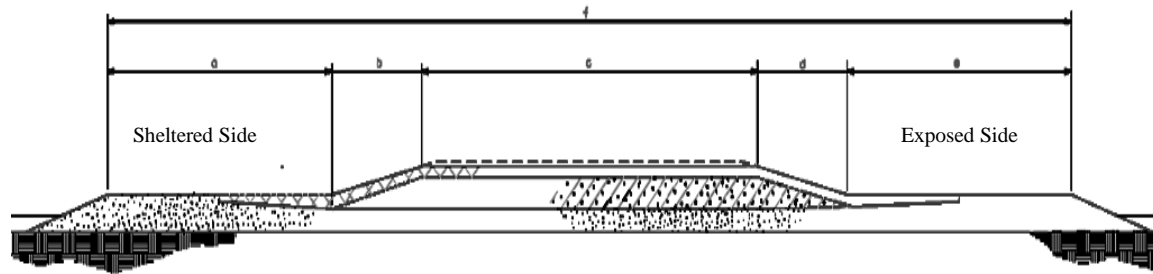
Table 3. Island Layout	
Design Category	Design Criteria
Geomorphic	<ol style="list-style-type: none"> 1. Restore a riverine flow regime by rebuilding natural levees along channels. For below bankfull flow conditions, the majority of the flow conveyance should be in channels. The ratio of floodplain to channel discharge during floods should be less than 1.0. 2. Identify erosion and deposition zones. Position islands to increase the magnitude of erosion and deposition in their respective zones and increase bathymetric diversity.
Hydraulic/Sediment Engineering	<ol style="list-style-type: none"> 1. Locate in shallow water to reduce costs and increase stability 2. Incorporate existing island remnants into new island for aesthetics. 3. Position perpendicular to flow and dominant wind fetch. 4. Position to shelter adjacent shallow areas and reduce sediment resuspension. 5. Maximize flow conveyance in existing channels.
Constructability	<ol style="list-style-type: none"> 1. Minimize access channel dredging, by positioning some reaches of islands close to deep water (1.5 meters in depth). 2. Construct over old island remnants to improve equipment stability.
Habitat	<ol style="list-style-type: none"> 1. Maximize habitat area sheltered by island. Islands should be positioned to shelter the maximum amount of shallow (< 1 meter depth) water area. 2. Create multiple habitat areas with visual barriers for waterfowl resting. 3. Create channel border habitat including dynamic littoral/riparian zone.

The general layout of the proposed design features is shown on Figure 5. The island layout was based on the design criteria given in Table 3. Specific Dimensions for the islands are given in Table 4.

Island Cross Section

The basic island cross section is shown on Figure 1. Dimensions for the island cross sections are given in Table 4.

Figure 1. Typical Island Cross Section



Name	Type	Elev_1912	Dim_A	Dim_B	Topwidth Dim_C	Dim_D	Sand berm width Dim_E	Sand berm Elevation	Dim_F	US SS	DS SS	Length feet
Rock Sill A	Rock Sill	622.5			10					3:1	3:1	281
Rock Sill D	Rock Sill	622.5			10					3:1	3:1	120
Rock Sill E	Rock Sill	622.5			10					3:1	3:1	70
Cobble Liner	Rock Sill	615.0			10					3:1	3:1	200
Island A	Rock Berm with narrow island	623.0	15		4		50	623.0		1.5:1	4:1	2420
Island B	Rock Berm with narrow island/pass lane	623.0	15		4		30	623.0		1.5:1	4:1	1930
Island C	Type A Island	628.4	30	30	40	30	40	622.0	170			200
Island C	Type A Island	626.5	30	25	40	25	40	622.0	160			300
Island C	Type A Island	625.0	30	20	40	20	40	622.0	150			370
Island C	Type A Island	624.0	30	15	40	15	40	622.0	140			570
Island C	Type A Island	622.5	30	10	40	10	40	622.0	130			200
Island D	Rock Berm with narrow island/pass lane	623.0	15		4		30	623.0		1.5:1	1.5:1	3200
Island E	Narrow island tied into existing w/vanes	623.0	30		30			623.0		1.5:1	4:1	920
Island E1	Rock Berm with narrow island/pass lane	623.0	15		4		30	623.0		1.5:1	4:1	440
Island F	Rock Berm with narrow island	623.0	15		4		50	623.0		1.5:1	4:1	1550
Island G	Type A Island	628.4	30	30	40	30	40	622.0	170			500
Island G	Type A Island	626.5	30	25	40	25	40	622.0	160			600
Island G	Type A Island	625.0	30	20	40	20	40	622.0	150			700
Island G	Type A Island	624.0	30	15	40	15	40	622.0	140			900
Island G	Type A Island	623.0	30	10	40	10	40	622.0	130			600
Island H	Rock Berm with narrow island/pass lane	623.0	15		4		30	623.0		1.5:1	4:1	1020
Island J	Rock Berm with narrow island/pass lane	623.0	15		4		30	623.0		1.5:1	4:1	1200
Island L	Narrow island tied into existing w/vanes	623.0	30		30			623.0		1.5:1	4:1	920
Island K	Type A Island	628.4	30	30	40	30	40	622.0	170			400
Island K	Type A Island	626.5	30	25	40	25	40	622.0	160			400
Island K	Type A Island	625.0	30	20	40	20	40	622.0	150			600
Island K	Type A Island	625.0	30	15	40	15	40	622.0	140			860
Island K1	Type A Island	623.0	30	10	40	10	40	623.0	130			847
Rock Mound I	Rock Berm	623.0			4					1.5:1	1.5:1	425

Island Top Elevation

The island elevations were based on the design criteria shown in Table 5.

Table 5. Island Elevation	
Design Category	Design Criteria
Geomorphic	1. Design elevation should be near or above bankfull elevations.
Hydraulic/Sediment Engineering	1. Island should be stepped down in elevation in the downstream direction. 2. Rock islands or sills should be placed at lower elevations than earth islands. 3. Earth berms on the side of island should be approximately 0.6 meters above average water elevations to provide optimum conditions for vegetation growth. 4. Minimize flood impacts.
Constructability	1. Island should be two feet above water to provide stable working surface. 2. Construction tolerance should result in desired microtopography
Habitat	1. Design elevation should provide desired vegetation. 2. Vary island elevations for vegetation diversity. 3. If island function includes nesting, the top elevation should exceed the level of the 20-percent chance exceedence flood event. 4. Mudflat and sandflat elevations should be 0.1 to 0.2 feet less than the average water surface elevation during the fall migration. If sediment deposition is expected, elevations could be lowered. 5. The size of the reduced wind zone immediately downwind of an island approximately equals 10 times the island or tree height.

The lower section of each island decreases in elevation in a downstream direction so that the lower ends of the islands are overtopped first during flood events. This reduces the hydraulic forces across the upper ends of the islands during overtopping. A wide distribution of the top elevations has been shown to improve vegetative species diversity and overall habitat quality.

Design elevations for the island sand berms are set at 1.9 feet above the average water surface elevation of 620.1. This elevation is above the average water surface elevation, but will be under water for minor floods. These berms provide protection against wave driven erosion and allow for the development of vegetation.

Island Widths

The island widths were based on the design criteria shown in Table 6.

Table 6. Island Width	
Design Category	Design Criteria
Geomorphic	1. Wider islands increase floodplain resistance during floods. Island width can be a factor in restoring a riverine flow regime (floodplain to channel discharge ratio less than 1.0 during floods).
Hydraulic/Sediment Engineering	1. Island width should be maximized to reduce erosion potential during floods. 2. Berm width should provide adequate material for beach formation and still allow a stable 5 meter strip for vegetation growth.
Constructability	1. A 30 meter width is minimum for hydraulic placement of dredge material.
Habitat	1. Width may affect island function as a migratory corridor (e.g. A top width of 50 feet may be needed to create a forest interior for neotropical migrants).

Island Side Slopes

The island side slopes were based on the design criteria shown in Table 7.

Table 7. Island Side Slopes	
Design Category	Design Criteria
Geomorphic	1. Wave action on shorelines with sand substrate results in 1V:10H or flatter.
Hydraulic/Sediment Engineering	1. Use side slopes of 1V:5H or flatter to reduce rill erosion due to rainfall 2. Where riprap is being used, side slopes should be 1V:3H or steeper to reduce rock quantities 3. If ice forces are a problem, side slopes should be 1V:4H or flatter.
Constructability	1. Constructing island features to a specified slope under water is difficult to build and inspect.
Habitat	1. Flatter slopes provide habitat for shore birds, wading birds, nesting turtles, and a variety of other species.

The only hydraulic design factor affecting island side slope was that slopes should be 1V:5H or flatter to minimize rill erosion due to local runoff.

Shoreline Stabilization

The shoreline stabilization was based on the design criteria shown in Table 8.

Table 8. Island Shoreline Stabilization	
Design Category	Design Criteria
Geomorphic	<ol style="list-style-type: none">1. Rock is needed when the combination of river currents, waves, or ice remove substrate from a reach of shoreline faster than it is transported in.2. Create dynamic shorelines with a beach zone.
Hydraulic/Sediment Engineering	<ol style="list-style-type: none">1. For river currents: use 18-inch riprap or biotechnical (e.g. offshore rock mounds, vanes, hardpoints, root wads, combined with vegetation).2. For wave action use biotechnical (e.g. rock groins and vegetation)3. For extremely convex shapes such as island tips use revetment.4. For extremely sheltered shorelines or those that have offshore water depths less than 1 foot use vegetative stabilization.5. Woody vegetation is needed for shoreline stabilization to provide rigid stems during the spring flood season.6. If ice action is severe, increase rock slopes to 1V:4H or flatter.7. Provide adequate material in berm for beach formation or construct 1V:10H or flatter beach.
Constructability	<ol style="list-style-type: none">1. Access to the site for trucks or barges hauling rock is the most critical factor
Habitat	<ol style="list-style-type: none">1. Create channel border habitat including littoral/riparian zone.3. Build sand flats and mud flats near islands in sheltered areas.4. Use biotechnical or vegetative stabilization when possible.5. Larger stone size provides better substrate for benthic organisms and fish.5. Include woody material (logs, stumps) in shoreline protection.

Shoreline stabilization used at Capoli Slough falls into 3 general categories; rock revetments, biotechnical, and vegetative. The rock revetments will consist of 24-inch layer of rock on a 1V:3H slope. Revetment will be used on shorelines exposed to significant flow velocities and on convex shorelines such as island tips. On shoreline reaches where rock revetment isn't used, the stabilization technique will involve construction of a 30 to 40 foot wide berm. The design elevations of the berm will be 622 feet, 1.9 feet over the average water surface elevation. In reaches that are extremely sheltered, vegetative stabilization of the berm will be used.

Vanes:

The rock vanes will have a longitudinal slope of four percent and will be angled upstream at 45 degrees from the edge of the island. The vanes in the deepest water, at least six feet deep, will be tree J-hook vanes, and the vanes in a medium water depth, about four to six feet deep, will be J-hook vanes. The tree diameter for the root wads is 1.5 to 2 feet and has a minimum of 3.5 feet of rock covering the tree.

Bank Protection of Existing Islands:

Bank protection was designed for existing islands 1, 2, 3, 4, 6, 7, and 8. Because each of these islands is located on the shallow shelf, the bank protection will be in the form of an offshore narrow island with a rock mound. The offshore rock mounds for islands 4, 6, and 8 along Capoli Slough and island 7 along the main channel may also incorporate root wads

through the rock mound to increase fish habitat. The rock mounds at the other islands are too shallow to incorporate root wads. The tree diameter for the root wads should be 1.5 to 2 feet and have a minimum of 4 feet of rock covering the tree.

An alternative to the rock mound would be a native material bank revetment. This would consist of trees, some with intact root wads, and rock placed on top of the trunks to keep them in place. The maximum fish habitat gained would be if the trees were almost completely submerged. This option would also provide loafing habitat for waterfowl. Because of the shallow shelf in almost the entire complex, most of the existing islands are set back from the banks. There is a lack of canopy on the stream banks for fish since there isn't any overhanging vegetation. The root wads would provide that canopy. A drawback to this bank protection would be that it would provide protection primarily at the water surface compared to a rock mound, which provides protection to 2 feet above the average water surface. A drawing is attached.

Another alternative to the rock mound would be a tree mound. Trees would be laid longitudinally along the streambank, overlapped and cabled together, and held in place by piles of rock. The drawback would be deterioration of the exposed wood.

Rock Size:

The rock thickness for revetments is set at 24-inch.

Rock Sills

To maintain floodplain flow, rock sills are included in the project. These sills serve to decrease the head differential across the sand islands during overtopping events and minimize increases in water surface elevation for extreme flood events such as the 1-percent chance exceedence flood. The sill structures will be rock with a top elevation one foot lower than the rock bank protection so they will be overtopped first. If a rock mound is not used, then the sill must be one foot below the top of the existing islands it's tying into.

Deep Riffles

Riffle-pools naturally occur in many channels with a typical spacing of riffles at 7 to 10 times the channel width. No riffles were observed on the bathymetry, but in the Capoli Slough channel there seems to be periodic deeper spots (pools) starting at about river mile 658.0. The pool at about river mile 658.0 is very well defined and deep, however as the slough flows downstream these pools become less well-defined and less deep. It is proposed to place two deep riffles in the Capoli Slough channel to create greater bathymetric diversity. The bank protection on either side of Capoli Slough helps better define the slough and provide tie-ins for the deep riffles at either side of the slough. The depths here are six to eight feet deep. The riffles will be constructed such that a four-foot deep channel is maintained over the riffle for safe boater access. It is proposed that two deep riffles be constructed although as few as one riffle could be constructed.

There are three options for the deep riffles, a rock liner, log liner and a W rock weir. The log liner would be constructed from tree trunks cabled together and anchored to the bottom by concrete blocks and rock. The rock liner and log liner should have a horseshoe shape in plan view with the legs at the downstream side. It is suggested that each type of riffle be used as an experiment to compare the effects of each structure. The maximum velocity at this location on April 27, 1994 was 1.5 fps with a Lock and Dam 9 discharge of 93,881 cfs.

Other Features

Suggestions have been made to include additional features into the Capoli Slough project. Features such as Mud Flats and Loafing Structures have been successfully incorporated into other projects since the original DPR design was done for this project. An emergent wetland/mudflat is proposed to be constructed on the south side of Island K. The low sand berm portion of Island K cross section (622.0) would be constructed along the outside edge of the designated emergent wetland area. This sand berm would serve as the containment berm for the material used to create the emergent wetland. The design elevation of the emergent wetland is 621.0, however, a relatively wide tolerance will be allowed (such as ± 0.5 foot) to provide a diversity of elevations within the mudflat to promote vegetation by a variety of species. The sand berm would be breached or allowed to erode naturally. The decision would be made after the emergent wetland is constructed and it can be determined how stable the material is.

Consideration to additional features will be given in the Plans and Specification Phase of this project.

Flood Plain Impacts

The project was designed so that it would not impact the 1-percent chance exceedence water surface profile. Island A is designed to be overtopped by the 50-percent chance flood event. For the 1-percent chance exceedence flood event, Island A will be overtopped by 10-feet and will not cause a stage increase above the existing 1-percent chance exceedence water surface profile. Other islands are parallel to the main channel and will also be highly submerged during a 1-percent chance exceedence flood event. The 0.00-foot impact on the 1-percent chance exceedence flood profile was verified with a 1-D hydraulic model.

Hydrodynamics

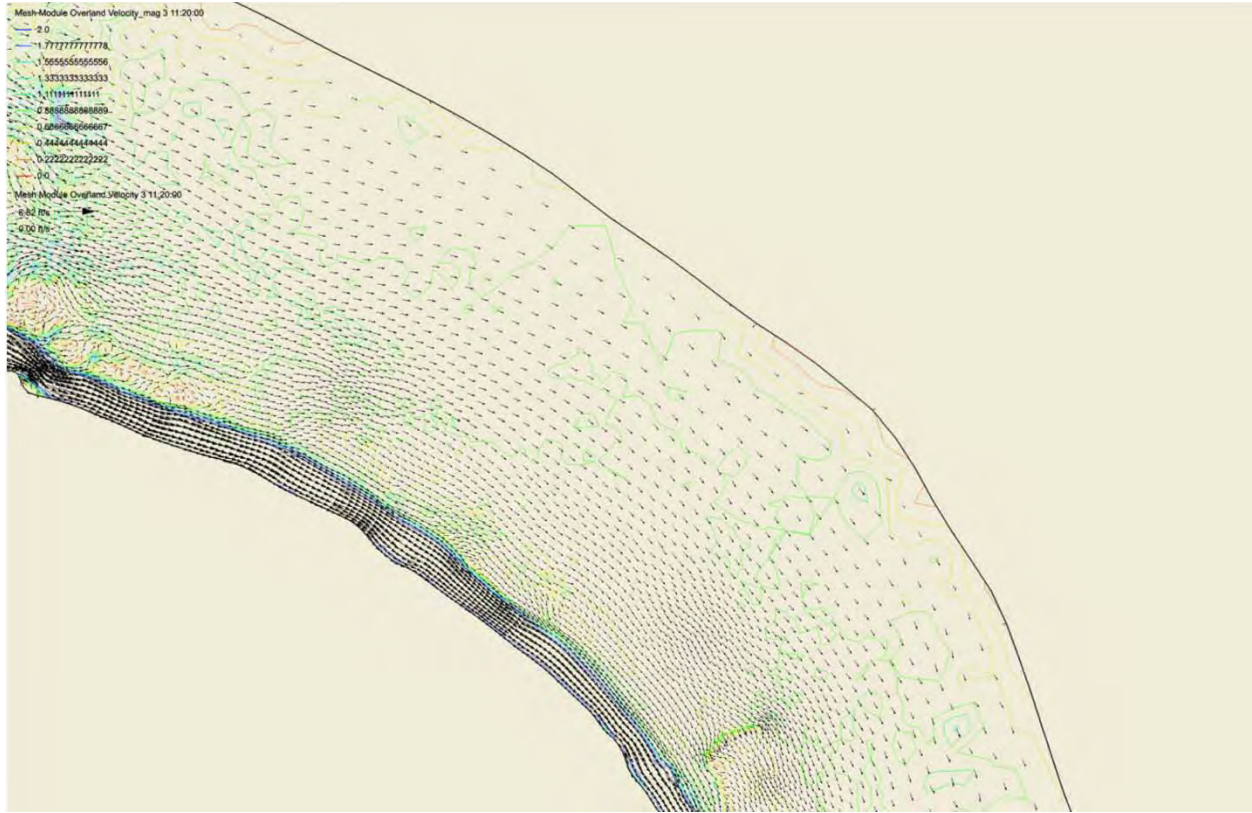
A two-dimensional hydrodynamic model was completed to evaluate island construction for this project. RMA-2 was used to simulate hydrodynamic conditions. For events up to the 50-percent chance exceedence flood, the interior area has velocities less than 0.1-fps. For flood events above the 50-percent chance exceedence flood velocities in the interior area increase and approach existing conditions velocities at the 4-percent chance exceedence event. The model results were used in the habitat analysis.

Proposed conditions velocity vectors for 30,000 cfs are shown in the figure below. Velocities for the island interior area are less than 0.04-fps.



Proposed Conditions Velocity Distribution 30,000 cfs

A 2-D ADH model of pool 9 was used to model existing conditions. A range of flow conditions were run in the model. The model results were used in the habitat analysis. An example of existing conditions velocity vectors from the ADH model are shown in the figure shown below.



Existing Conditions Velocity Distribution 80,000 cfs

Figure 2: Project Vicinity Map

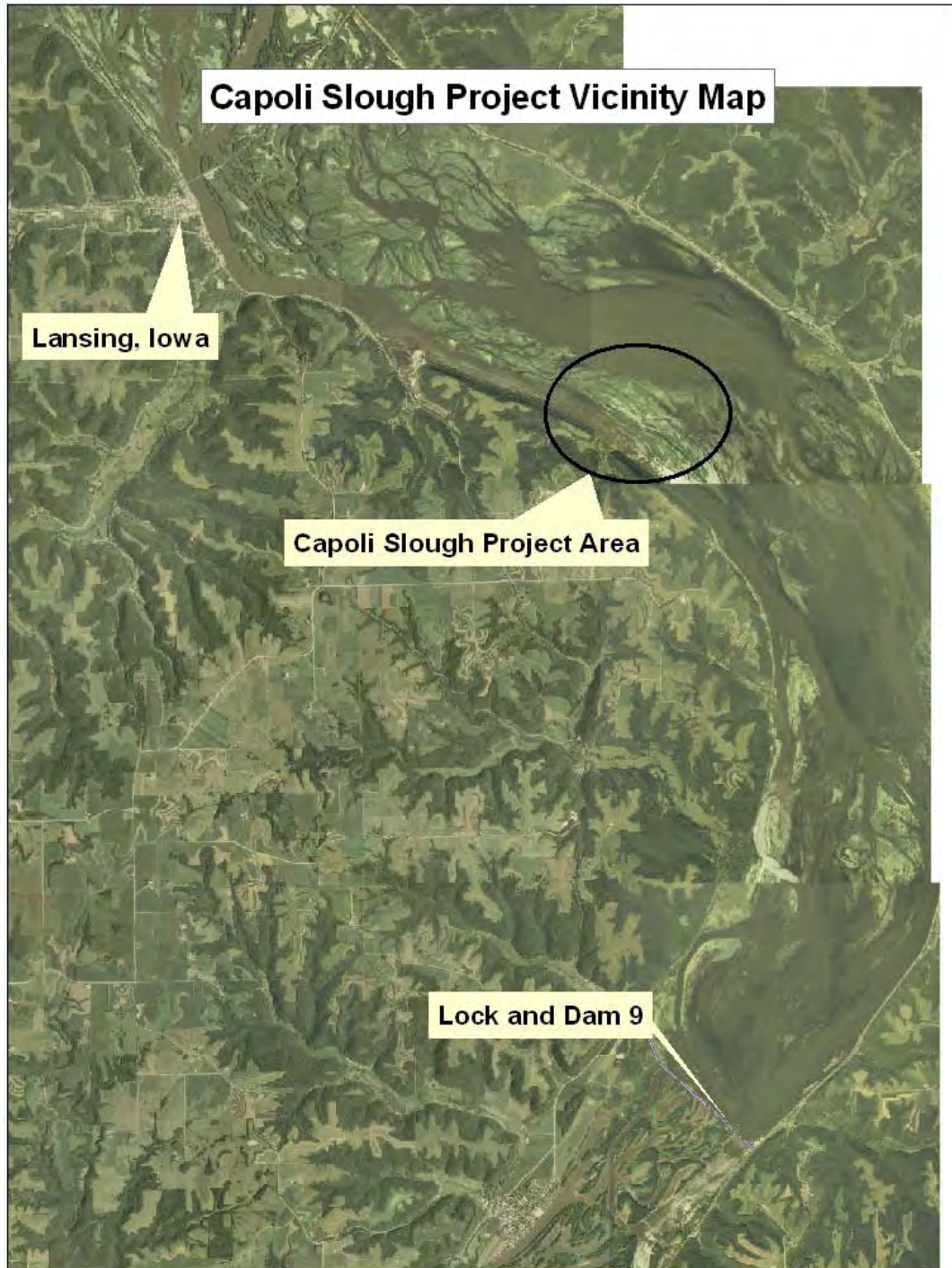


Figure 3: Bathymetry Map of Project Area

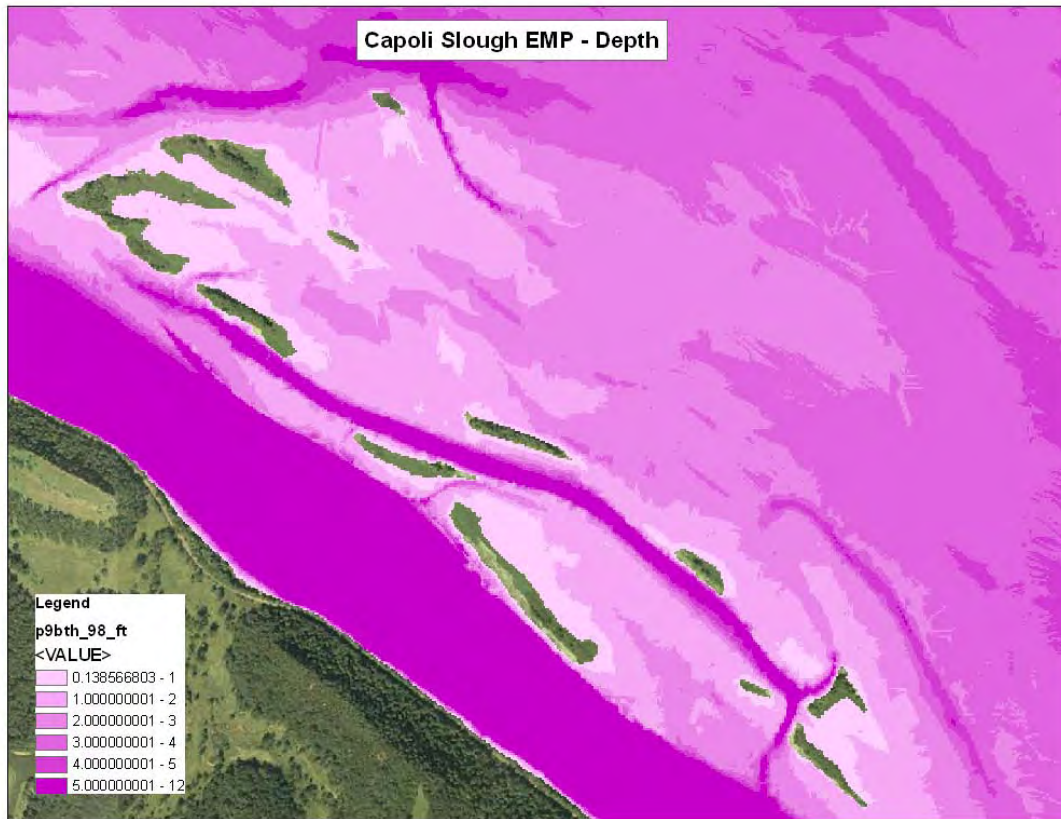


Figure 4: Map of Discharge Locations

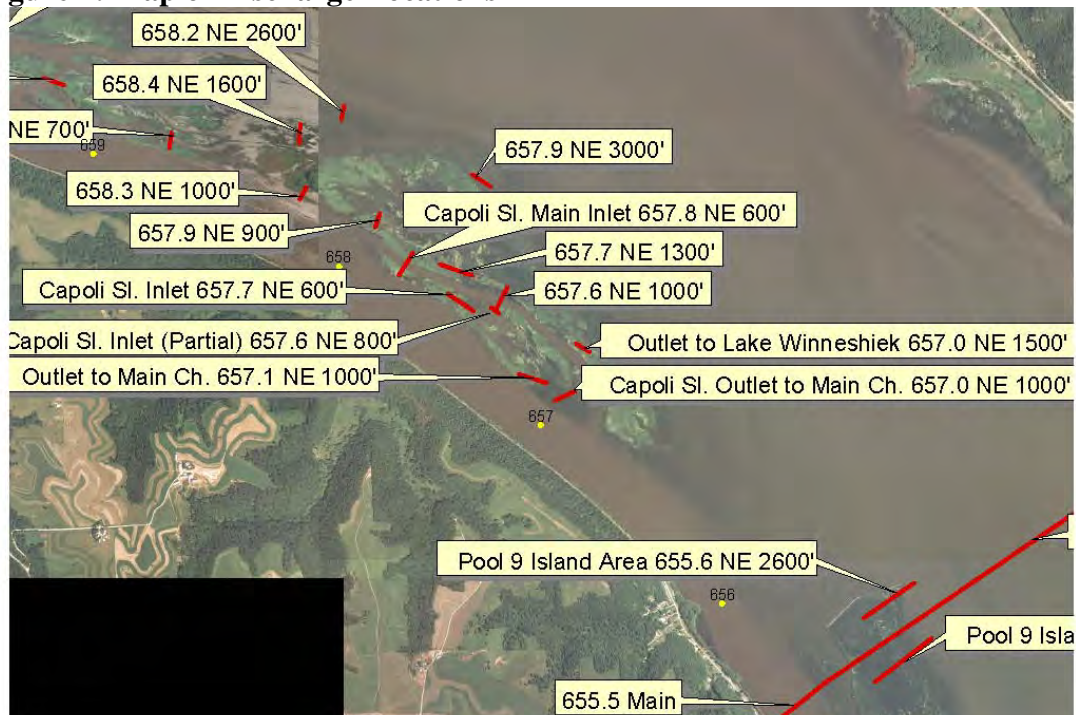


Figure 5: Layout of Project Features

